Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 23 (2011) 46 – 52

Procedia Engineering

www.elsevier.com/locate/procedia

Reseach on the failure and material selection of Plastic mold

Bohai He

Department of Numerical Control Engineering, Zhejiang Industry Polytechnic College, Shaoxing, Zhejiang, 312000, China

Abstract

The working conditions of the plastic mold are complex. They touch directly with the plastic, withstand the pressure, temperature, friction and corrosion and so on. The main failure modes of the plastic mold surface wear, deformation and fracture. The main failure reasons depend on working conditions,mold materials and heat treatment,etc.So material selection and heat treatment of the plastic mold are more important. Material selection of plastic mold is decided by their using performances.According to the mold types, material types and performance requirements,we select different heat treatment.

Selection and/or peer-review under responsibility of [name organizer]
Key words: plastic mold, failure, material selection, heat treatment

1 Introduction

In China, the plastic product takes a more and more important role in the national economy. Plastic production by volume in the world has exceeded steel production. The proportion of plastic mold production in the total mold production is increasing year by year. It consumes a large quantity of steel,has different specifications and more complex structure,has low surface roughness requirement,but It is difficult to manufacture it. Therefore, It has become an important research topic that comprehensive analyses plastic mold working conditions and failure on the basis of how to reasonable choose plastic mold materials in order to increase it's working life, assurance it's quality, reduction it's cost. But the plastics industry in China started late, the research in this area is still not deep enough.

We should understand the basic requirements of plastic mold parts molding when analyse plastic mold working conditions and failure modes. First of all, the appearance requirements of plastic parts are very strict, especially in clear plastic parts, which requires the mold formed surface has low roughness, generally in the range of Ra0.2～0.025mm or less, a small amount of wear or corrosion can lead to the failure of important working parts such as cavity or core of mold. Secondly, the dimension accuracy requirements and reciprocal accuracy requirements of the molding part are high, in order to ensure juncture closed and avoid overflow or juncture trace on plastics surface. In addition, when the shape of plastic mold parts is complex, the mold cavity structure is correspondly complex, which results stress

doi:10.1016/j.proeng.2011.11.2463

concentration in parts of the cavity, and affects the carrying capacity of the mold. Because these three reasons are related to mold precision machining , which makes it difficult to manufacture plastic mold, manufacturing costs increase. Therefore, it is of great significance to prevent the early failure in the plastic mold.

2 The working conditions of plastic mold

The working parts of plastic mold mainly consist of the cavity, core, inserts, molding and forming ring. They form the plastic mold cavity and a variety of surfaces of plastic parts. They touch directly with the plastic, withstand the pressure, temperature, friction and corrosion and so on.

Plastic injection mold cavity pressure is generally at 40～140MPa, closed die pressure is at 80～300MPa or more.Heating temperature is at 140～300℃, the specific parameters are related to the variety of plastics. Cavity surface withstand friction and corrosion, and its intensity depends on the type of plastic and the nature of the filler. For manual mold, such as portable compressed molding or pressure injection molding, in installing mold and releasing mold,mold often knocked by hand percussion instruments and collision.

3 The main failure modes of plastic mold

The basic forms of failure of the plastic mold are surface wear, deformation and fracture, because the requirements of the surface roughness and precision of plastic products are high, wear and tear on the mold surface take up a larger proportion of failures.

3.1 Surface wear failure and the main failure reasons

Thermosetting plastics flows on the surface of the mold serious friction, causing the surface roughness of the cavity or core surface increase. This will definitely affect the appearance quality of suppression parts, which needed to be removed and regular polished. After repeatly polished, the cavity comes to failure due to size tolerance.

When plastics contains mica, silica sand, glass fibers and other solid inorganic filler, it will significantly increase die wear. This not only causes rapid the deterioration of cavity surface roughness, but also causes dramatic changes in the mold cavity size.

If plastic contains elements such as chlorine, fluorine, it will precipitation HC1, HF and other strong corrosive gases when heated, corrode

mold surface,results in mold failure. If corrosion comes with wear ,the two cross-injury will aggravate the failure of mold.

3.2 The main reason of the plastic deformation failure

Bakelite mold made in carburization of steel or carbon tool steel, especially small mold which is used overloaded in large-tonnage compressors, is more susceptible to produce overload plastic deformation. There may be sag, pitting, surface wrinkling in other parts of the cavity. Especially plastic deformation is more prone to produce in the edges and corners.

The main reasons of the plastic deformation failure are that the hardened layer in the surface of the mold cavity is too thin,and lack of deformation resistance,or working temperature is above tempering temperature and lead to the phase transition and soften, leaving the mold failure early.

3.3 Fracture and Deformation failure and the main failure reasons

When the plastic cavity structure is complicated, while pressure it withstands is large, parts of cavity may be in a complex stress state, coupled with the stress concentration caused by structural factors, which may produce mold fracture.

The main failure reasons are due to structural faults, temperature stress resulting from structure, thermal stress or insufficient tempering, at working temperature, residual austenite changes into martensite, which induce partial volume expansion and internal organization stress in mold.

So,much attention should be put on the mold design, fully temper measure should be taken in heat treatment, the more important thing is using toughness steel to make plastic mold, using high toughness steel (penetration carbon steel or hot work die steel)to make large and medium-sized complex bakelite mold cavity.

3.4 Fatigue and thermal fatigue failure and the main failure reasons

The mechanical load of plastic mold is cyclical change. For example, in the filling and packing period of injection mold, cavity withstands the high-pressure of plastic melt tension, and in the cooling and stripping stages, outer load is completely removed. Repeatly working one after another, the cavity surface withstands pulse tensile stress, which may cause fatigue failure.

Heat load of Plastic mold is also cyclely change. For example, the melt material temperature injected into the cavity is generally around 200℃ or higher, while the cool temperature after hardening is about 50℃. Repeatly heating and cooling , stress concentration may occurs in cavity surface which can lead to thermal fatigue crack. Coupled with the pulse tensile stress of cavity surface, the thermal fatigue crack may expand depth, which are the crack sources of fracture or fatigue fracture.

Under normal circumstances, compressing mold whithstands a larger force, easyly produce fatigue cracking; injection mold temperature changes more rapidly, easyly produce thermal fatigue cracks.

4 The performance requirements of Plastic mold material

The main forms of plastic mold failure are wear, corrosion, deformation and fracture. Material selection and heat treatment of plastic mold should be based on the performance requirements of the size of the mold, shape, working conditions and failure, including the use of both the material properties and process performance.

4.1 Requirements on the using performance of materials

These material performance requirements on mold depend on the nature of the processed plastic and surface quality that plastic products required:

1) When the processed plastics contains hard filler, the hardness and wear resistance requirements of material are high.

2) When corrosive substances is precipitated in the plastic molding process, material corrosion resistance is required.

In general, thermosetting plastics contains solid fill, and the cross-linking reaction, often release chemical gases and other substances, which requires that material also has the performence of high wear and corrosion resistance.

3) When the plastic products have a high surface quality requirement, the light and small damage on the mold surface is enough to cause mold failure, the mold need to be re-polished and can continue to use, which makes the higher requirements of wear and corrosion resistance on mold material.

These performance requirements of mold material depend on die pressure, work frequency, impact load and size and complexity of mold.

When the work temperature of mold is high, the local surface of the mold cavity is under the combined effect of pressure and temperature ,which may produces temper softening and plastic deformation, or produces surface tensile stress due to annealing changes.In addition ,the result of alternating heat load generates thermal fatigue cracks. At this time, requires material have the thermal conductivity, a certain degree of hot strength and thermal fatigue resistance .

4.2 Processing performance requirements on material

Most of the plastic mold requires high precision, surface quality, process performance requirements of material is very prominent. Which makes it difficulty to manufacture mold and causes the cost of mold increase, thus:

1)Good cutting processing and surface polishing When the plastic products is complex in shape, and has high surface quality requirements, or has fine pattern on the surface, which requires the mold material facilitate cutting, suitable polishing, and a good light etching . In particular, plastic mold needed to be pre-hardened, the pre-heat treatment meets 35～45HRC hardness requirements, no heat treatment is needed after machining,in order to ensure dimensional accuracy and surface roughness. This requires material in a state of high hardness is still a good machinability. The material properties of Polishing and light etching requires high metallurgy quality, less non-metallic inclusions, homogeneous fine, high hardness and uniform.

2)Good processing of heat treatment and surface treatment High precision plastic molds,requires the heat treatment process of material simple and deformation small. The mold requires wear and corrosion resistance, requires that materials can be improve the corresponding properties of the surface by surface treatment and will not adversely affect the overall performance.

3)Other manufacturing processing For the mold using cold extrusion to forming cavity, requires that material is plastic deformation resistance of small after annealing; large and complex molds requires that material has good welding process in order to be able to easily repair local damage and so on. The cost of plastic mold is high, generally is about 75% of the total cost, while the cost of materials and heat treatment is about 10% each. Thus, the more important plastic molds, under the premise of good performance should choose easily manufacturing materials, and the price factor is of secondary fact.

5 The choice of plastic mold materials

5.1 Cold forming plastic mold material selection

For this type of mold we usually select low carbon steel (carburizing steel) and strive to choice low-carbon or very low carbon steel such as DTl, 20,20 Cr, 12 Cr Ni3 A, 40Cr and so on.

For the injection, extrusion forming molds that have high wear-resistant surface and heart department toughness good and less complex in shape ,we can use carburizing steel to cold forming mold. we also use 10,20,12 CrNi3A, 20Cr,20CrMhmo and 20Cr2Ni4A,etc.

5.2 Cutting molding plastic mold material selection

Mailly use quenched and tempered steel after quenching and tempering treatment processing.

1)Small production, or small molds can use quenched and tempered carbon steel, such as 40,50,55, etc.

2)large quantities or large, complex molds can use alloy quenched and tempered steel, such as 3Cr2Mo, 4Cr3MoSiV, 5CrNiMo, 5CrMnMo, 4Cr5MoSiV, 4Cr5MoSiVl ,etc.

3)High-precision,large quantities injection molding, we choice pre-hardened steel ,such as 4Cr5W2SiVl, 8Cr2MnWMoV. Pre-hardened hardness is about 42～48HRC. Sometimes we choice pre-hardened cutting steel.

Working conditions	Recommended steel
small plastic mold with small production and less precision products	45、55 or 10 Carburizing steels、20 Carburizing steels
withstand a larger dynamic load, producing larger quantities, more serious wear	12CrNi3A、20Cr、20CrMnMo、20Cr2Ni4A Carburizing steels
Large, complex, large volume, injection molding or extrusion dies	3Cr2MO、 4Cr3M03SiV、 5CrNiMO、 5CrMnMO、 4Cr5MoSiV、4Cr5MOSiVl
Thermoset molding requiring high wear, high strength	9Mn2V、7CrMn2WMO、CrWMn、MnCrWV、 GCrl5、5Cr2MnWMOVS、Cr2Mn2SiWMoV、 Cr6WY、Crl2MOV、Crl2
Corrosion resistance and high-precision plastic mold	4Crl3、9Crl8、Crl8MoV、Crl4Mo、Crl4M04V
Complex, sophisticated, high wear-resistant plastic mold	25CrNi3MoAl“Ni(250)、18Ni(300)、18Ni(350)`

6 Plastic mold heat treatment

Plastic mold should have a moderate hardness and good toughness, different types of mold requires different hardness, several types of plastic mold steel and hardness of the requirements are show below. As thermosetting plastic mold is heated and works under pressure in a long time, through heat treatment, has a high enough resistance to pile collapse capacity.

The work hardness of different types of plastic mold

Mould type	Die steel	Work hardness	Description
plastic with a simple shape and inorganic filler	Crl2Mo or 5CrW2Si Carburizing steels	56～60HRC	Requirs wearability under high pressure
small plastic mold with a simple shape and a long life	alloy tool steel such as 9Mn2V、Cr12 etc	54～58HRC	high wearability and good strength and toughness
high precise plastic mold with a complex shape and a micro-deformation quenching	T7A、T10A	45～50HRC	Parts for easily broken (eg, core)
Soft injection plastic mold	Carbon tool steel、3Cr2Mo	280～320HBS	Soft plastic filler-free

(1) During mold heat treatment, special attention should be put on protecting the cavity surface to prevent surface oxidation, corrosion, decarburization or carbon. If the surface carbon content is too high ,it will cause an increase in retained austenite, it is difficult or impossible to finish. Quenching should be used more moderate and the cooling medium, so as to avoid deformation and quenching crack. It is necessary to use delaying cooling quenching or heat-bath quenching or air-cooled.

(2) Easy cutting pre-hardened steel can avoid quenching and deformation; Martensite aging steel or high-quality low-alloy aging steel can control the deformation rate less than 0.05%; between roughing and finishing or before precise finishing using removing stress treatment, can remove residual stress caused by manufacturing deformation; using reasonable heat treatment process, the die steel is in stable organization to avoid the distortion caused by tissue changes; using low coefficient of thermal expansion steel can reduce the deformation caused by thermal expansion and contraction.

(3) die should be fully tempered, tempering temperature should be higher than the working temperature, so as tempering changes not to continue at work, and thus occur stress on the surface of cavity.

(1) The requirements of the carburized layer

After Molds made in the type of steel are carburized ,their surface has high wear resistance and heart ministry maintain high strength and toughness, so as to avoid the early wear and brittle fracture.

Carburized layer thickness: when mold is used to pressing hard plastic parts , the thickness of carburized layer is 1.3～1.5mm;when suppress soft plastic parts, the thickness of carburized layer is 0.8～1.2nnn; mold with sharp corners, and thin edges, taking diffusion layer 0.2～0.6mm.

Carburized layer chemical composition: Itis appropriate that carbon content in carburized layer is of 0.7%～1.0%, too high carbon content would increase the amount of residual austenite, deteriorate polishing performance. If mold are carbonitriding, their surface abrasion resistance,oxidation resistance, corrosion resistance and anti-adhesion are better than a single Carburized layer.

Infiltration layer: should avoide coarse undissolved carbide, carbide network, such as excessive retained austenite.

(2)Carburizing process: It is appropriate to adopt the classification of carburizing process, that is ,the temperature at 900～920℃ is used to rapid carburizing,while moderate temperature(820～840℃) is used to increase the carburization thickness mainlly.

Carburizing temperature: generally at 900～920℃, a small complex cavity mold preferred temperature is at 840～860℃ for carbonitriding permeation.

Holding time: Selection carburizing holding time according to the requirements of the infiltration layer thickness. Holding time is different that access the same thickness of diffusion layer for carburizing different ways,such as solid Carburizing and gas carburizing.

(3)Quenching process after carburizing according to different type of steel,after carburizing different processes are used: re-heating and quenching;direct quenching after carburizing grade (such as carburizing alloy steel);after the medium temperature carbonitriding directly quenching (such as industrial pure iron or small precision and cold formed molds with low carbon steel);carburizing quenching followed by air cooling (such as high alloy steel carburizing mold with large and medium-sized).

References

[1]Feng Xiao Zeng, Heshi Yu, Guo Baolian. Failure Analysis of Die. Beijing: Mechanical Industry Press, 1987

[2]Shimei Tang. The heat treatment performance of common tool steel. Shanghai: Shanghai Science and Technology Press, 1984

[3]Ye Yuhua. Plastic mold steels and their performance requirements. Conference papers die steel materials. Huazhong Institute of Technology, 1986

[4]Cheng Peiyuan. Zhao zhong-zhi. life and material of mold. Wuhan: Wuhan Institute of Technology Lecture, 1994

[5]Zhang Luyang.Die failure and protection. Beijing: China Machine Press, 1998